The ARSIS method: a general solution for improving spatial resolution of images by the means of sensor fusion

Thierry Ranchin, Lucien Wald, Marc Mangolini

THE ARSIS METHOD: A GENERAL SOLUTION FOR IMPROVING SPATIAL RESOLUTION OF IMAGES BY THE MEANS OF SENSOR FUSION

Thierry Ranchin[1], Lucien Wald[1], Marc Mangolini[2]

[1]Groupe Télédétection & Modélisation, Centre d'Energétique, Ecole des Mines de Paris
Rue Claude Daunesse, B.P. 207 • F-06904 Sophia Antipolis cedex, France.

[2]Aérospatiale, SE/TNA, B.P. 99, 06322 Cannes La Bocca cedex

ABSTRACT: The Earth Observation satellites provide images with different spatial and spectral resolutions. This communications presents a method for increasing the spatial resolution of remotely sensed images by the means of an injection of structures extracted form the best spatial resolution image available in the set of images. One of the properties of the method is to preserve the original content of images when improving their resolution. This method is presented in the general case and two examples of application are presented. The benefits of using this method are enhanced.

1. INTRODUCTION

Since the first Landsat, the Earth observation satellites are presenting, in a lot of cases, different spatial and spectral resolutions. The Thematic Mapper sensor of Landsat satellites provides six images acquired from the blue band to the infrared band with a spatial resolution of 30 m and one thermal infrared band with a spatial resolution of 120 m. The HRV sensor of the SPOT satellites provides one image called panchromatic P with a spatial resolution of 10 m and a spectral range of 0.51 to 0.73 µm, and three multispectral images called XS1, XS2 and XS3 with a spatial resolution of 20 m and a spectral range of respectively 0.5 to 0.59 µm, 0.61 to 0.68 µm and 0.79 to 0.89 µm.
The future of Earth observation will follow the same model. SPOT 4 will provide a spectral band equivalent to XS2 with a spatial resolution of 10 m, two multispectral bands equivalent to XS1 and XS3 and a new band called MIR (Middle InfraRed) with a spatial resolution of 20 m. A new sensor called VEGETATION will be added on the platform and will provide images in the same spectral bands but with a spatial resolution close to 1 km. The SPOT 5-6 satellites are announced with a panchromatic band at the spatial resolution of 5 m and multispectral bands with a spatial resolution of 10 m. The Enhanced Thematic Mapper of Landsat 7 will deliver the same set of images as the previous satellites but a panchromatic band with a spatial resolution of 10 m will be added. Before the end of the century, new civil missions are planned with sensors that will deliver an image with a very high spatial resolution (1 or 2 m) and multispectral bands (spatial resolution: 4 or 8 m).
The end-users of these data often want to combine the high spatial and the high spectral resolutions in the aim of obtaining the most complete and accurate (in terms of spectral band) description of the observed area. Hence a lot of methods were proposed in order to simulate images having the best spatial resolution available in the set of images. In the case of the SPOT imagery, an analysis of these methods has shown that in terms of preservation of the spectral content of original images, none of them brings satisfying results. The authors have therefore defined a new sensor fusion method allowing the improvement of the spatial resolution of images up to the best available in the set of images and the preservation of the spectral content of original images. This method called ARSIS, after its french name "amélioration de la résolution spatial par injection de structures", was defined in the general case. It makes use of the wavelet transform and the multiresolution analysis and is presented in section 2. Two examples are proposed in section 3: its application to the case of

the SPOT imagery, and its application to the merging of SPOT XS images and the image provided by the russian sensor KVR-1000 in the panchromatic band with a spatial resolution of 2 m. The benefits of using the ARSIS method are discussed.

2. THE ARSIS METHOD

For all the merging processes, some pre-requisites are needed:

- images have different spatial and spectral resolutions,
- images to merge represent the same area,
- images are superimposed,
- no major change has occured in the area.

If the last requirement is not satisfied, the aim of the merging process can be the updating of the observed area. These requirements are not limiting the merging process to images acquired by the same platform. The process can also apply to the merging of images acquired by airborne and spaceborne sensors. Many methods have been proposed to enhance the spatial resolution of images taking advantages of the presence of one or more images with a better spatial resolution (see for example Carper *et al.* 1990; Chavez *et al.* 1991). But, if one of the objectives is to bring each image at the best spatial resolution available, while retaining all the spectral content of the image to enhance, only a few of them satisfy it. A comparison of the most representative merging processes has been achieved by Mangolini *et al.* (1995).
In order to fulfil this objective, the ARSIS method was first designed for the SPOT imagery and then generalized to be applied to the merging of images with different spatial and spectral resolutions. This method makes use of the wavelet transform and the multiresolution analysis. The multiresolution analysis was derived from the Laplacian pyramid by Mallat (1989). This mathematical tool can be represented by a pyramid as in Figure 1.

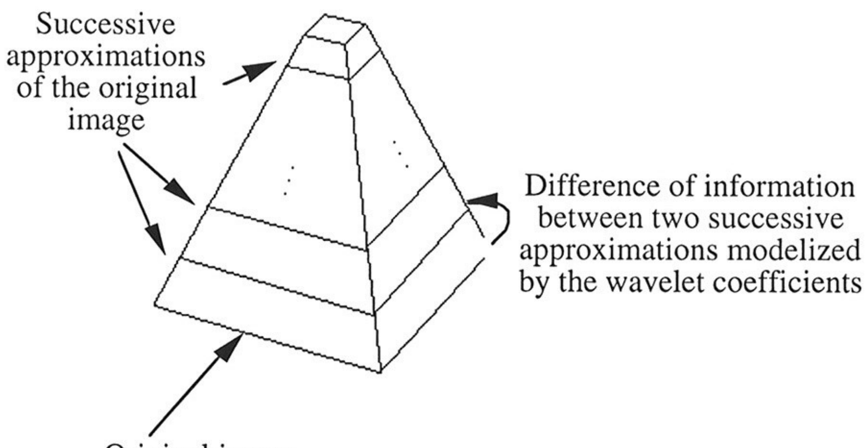

Fig. 1. Pyramid representing the multiresolution analysis combined with the wavelet transform.

The base of the pyramid is the original image. Each floor of the pyramid is an approximation of the original image computed from the original one. When climbing the pyramid, the successive approximations have coarser and coarser spatial resolutions. The theoretical limit of a multiresolution analysis is one pixel representing the mean of the original image. Due to some physical constraints this limit is never reached. The base of the pyramid can also be considered as an approximation of the landscape measured by the sensor. Associated to the multiresolution analysis, the wavelet transform allows the description of the differences existing between two successive approximations of the same image, of two successive floors of the pyramid, by wavelet coefficients. If the process of the multiresolution analysis is inversed, the original image can be exactly reconstructed, from one of the approximations and from the different wavelet coefficients computed between the original image and the selected approximation. These tools allow a hierarchical description of the information contained in the image. Some potentialities of these tools were proposed by Ranchin and Wald (1993). The ARSIS method uses these mathematical tools to describe the two images to merge as in Figure 2. The wavelet coefficients provided by a multiresolution analysis of the high spatial resolution image A describe the missing information for the synthesis of the image B at the same spatial resolution than the one of image A. The inversion of the multiresolution analysis allows the computation of the synthetic image B.

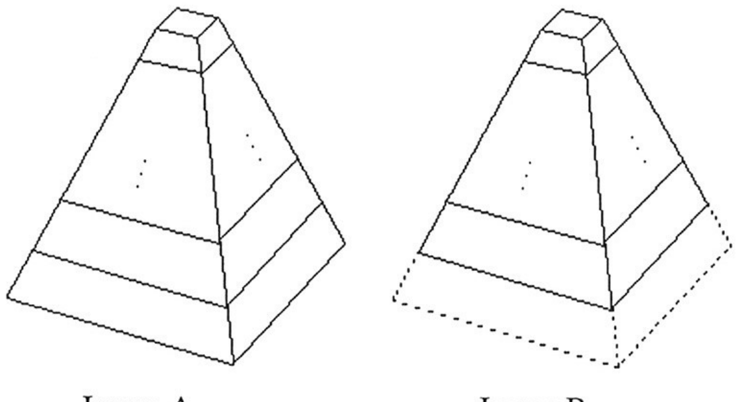

Fig. 2. The use of the multiresolution analysis in the ARSIS method.

Hence by construction, the ARSIS method preserves the spectral content of original image. A multiresolution analysis applied to the synthesized image B will allow the computation of an approximation equal to the original image B. If the wavelet coefficients provided by the image A are used without modifications, the synthesized image B will not be equivalent to "what will be see by the sensor B if it has the spatial resolution of the image A". Hence, to improve the quality of the synthesized image, a physical model is computed to transform the wavelet coefficients provided by the multiresolution analysis of the image A in the wavelet coefficients needed for the synthesis. Figure 3 presents the general scheme of the ARSIS method. First a multiresolution analysis using the wavelet transform is used to compute the wavelet coefficients and the approximations of image A (1). The same operation is applied to the image B (2). The wavelet coefficients provided by each decomposition are used to compute a model of transformation of the known wavelet coefficients of image A to the known wavelet coefficients of image B. This model takes into account the physics of both images and the correlation or anti-correlation existing between both wavelet coefficients images (3). This model is then used to compute the missing wavelet coefficients (4). The inversion of the multiresolution analysis (WT^{-1}) allows the synthesis of the image B with the spatial resolution of image A (5).

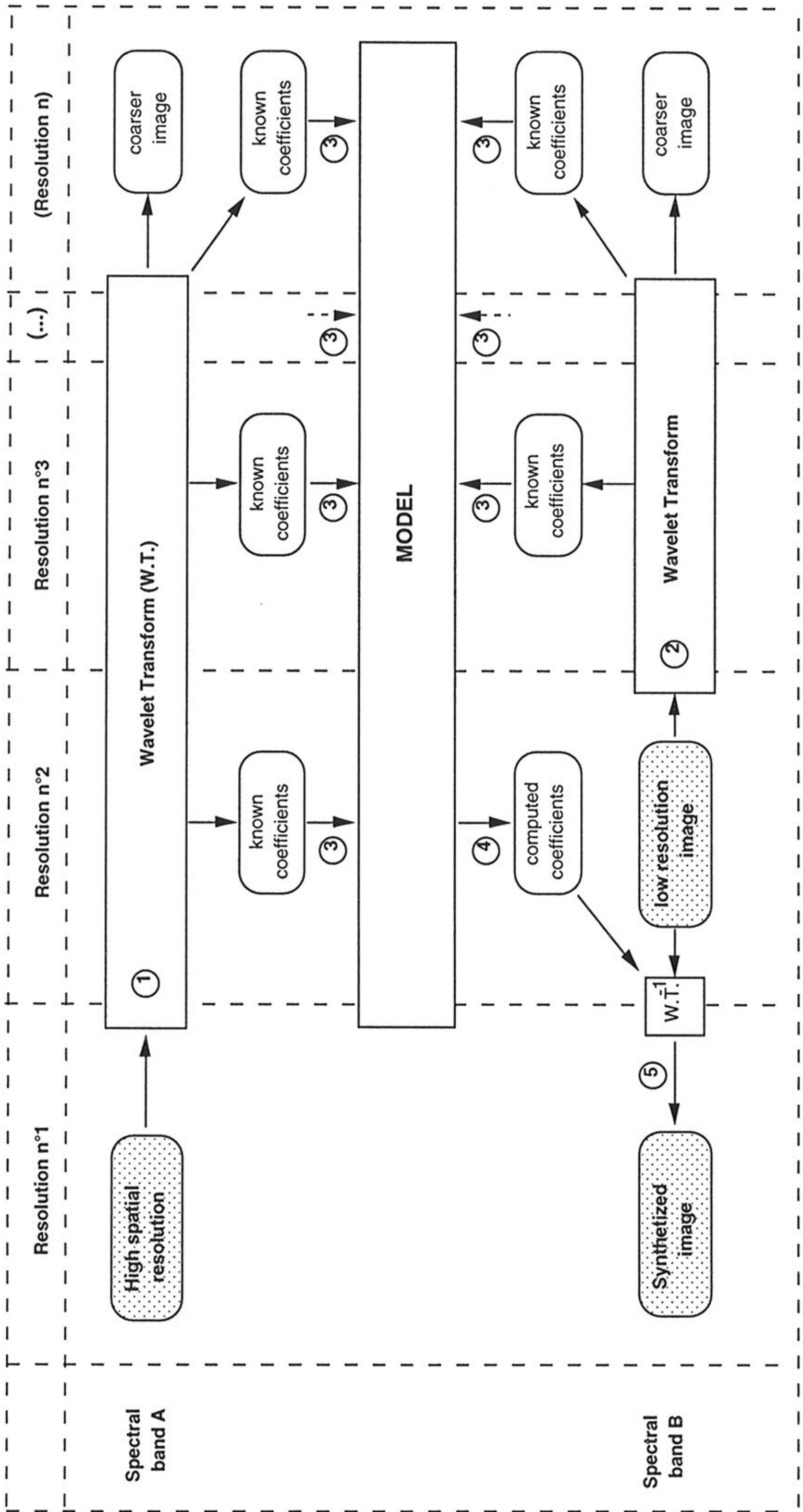

Fig. 3. General scheme of the ARSIS method

3. EXAMPLES

The first example deals with the SPOT imagery. The set of images was acquired in September 11, 1990 over Barcelona (Spain). Barcelona is a large city located in the north-east of Spain, on the Mediterranean seashore. The complete area presents a harbour, an airport, urban areas with roads and motorways, rivers, agricultural lots, montaneous areas and a Mediterranean vegetation. The set of images comprises a panchromatic image with a spatial resolution of 10 m and three multispectral images XSi (i = 1 to 3). The images were acquired simultaneously and are exactly superimposable. The ARSIS method allows to synthesize the multispectral images (image B) with the spatial resolution of the panchromatic image (image A), *i.e.* 10 m. The resulting images are called XSi-HR. Figure 4a presents an extract of the XS1 image at the spatial resolution of 20 m. This extract contains agricultural lots mixed with urban area. The roads and the motorways are clearly visible, though, the interchanges on the motorways are difficult to distinguish. A comparison between the XS1-HR image and the XS1 image is presented in Figure 4b. The original XS1 image was interpolated with a near-neighbour process. The visual quality of the XS1-HR image is due to the injection of the information extracted from the panchromatic image and modelized in order to preserve its spectral quality.

Fig. 4a. Original XS1 image (20 m)

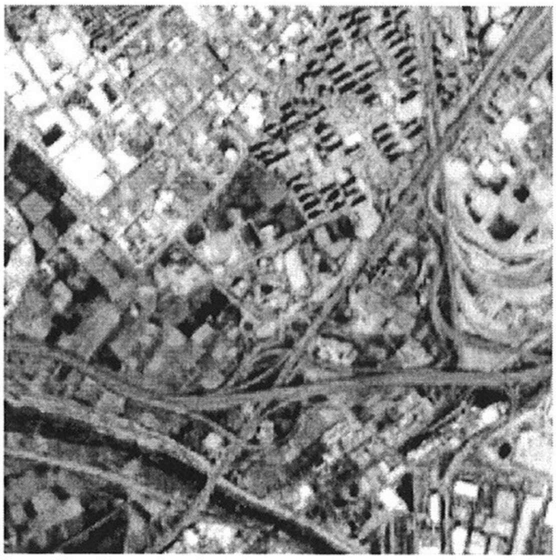

Fig. 4b. Synthesised XS1-HR image (10 m)

On the XS1-HR image, one can clearly distinguish the interchanges on the motorways, the road network in the upper left corner of the image and the large buildings. Mangolini *et al.* (1995) proposed a method to evaluate quantitatively the different sensor fusion techniques. ARSIS was shown as given the best results in terms of preservation of the spectral quality.

In the second example, the set of images is composed by a SPOT XS scene of the town of Ryadh (Saudi Arabia) acquired in May 16, 1993 and a russian image KVR-1000 of the same area acquired in September 7, 1992. The three multispectral images (image B) have a spatial resolution of 20 m and the KVR-1000 image (image A) has a spatial resolution of 2 m and a spectral range of 0.51 to 0.71 μm. Figure 5a presents a composition of the original XS images. The ARSIS method allows the computation of XS images at the spatial resolution of 2 m. Figure 5b shows a composition of this synthesized images. In this case, the gap between the spatial resolution of the image A and of the image B is important. This area is composed of a large interchange of two urban motorways, a lot of buildings and some sandy areas. The large object at the right side of the motorway in the lower part of the Figure 5b, is a mall. Due to the small details which appear in the synthesized image it is possible to distinguish the structures of this mall, and all the buidings in this area. The preservation of the spectral content of Figure 5a, allows the application of a classification, automatic or not, in order to extract the roads, the buildings.

The images synthetised by the ARSIS method were shown to preserve the spectral content of the original images. Hence, they can be used for classification, or for other methods that need to use the multispectral content provided by the whole set of images with the best spatial resolution available. Ranchin and Wald (1995) have shown the improvement brought by the use of the ARSIS method, to extract roads in urban areas by the means of classification methods.

Fig 5a. Composition of the original XS images

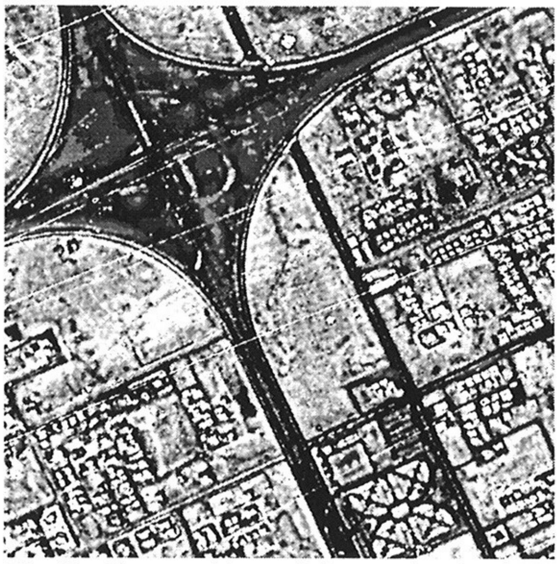

Fig 5b. Composition of the synthesized XS images (2 m)

4. CONCLUSION

The ARSIS method, a new sensor fusion method based on the multiresolution analysis and the wavelet transform was proposed. By construction, ARSIS imposes the preservation of the spectral content of original images when improving the spatial resolution of the images. The synthesized images can be used for other purposes than visual interpretation. The ARSIS method was successfully applied to the case of the SPOT imagery, to the merging of the XS images and the KVR-1000 image, and also to the merging of Landsat Thematic Mapper 6 (120 m) with the other bands of Landsat TM, the merging of Landsat TM and SPOT panchromatic images.

REFERENCES

Carper, W.J., Lillesand, T.M. and Kiefer, R.W., 1990. The use of Intensity Hue Saturation transformations for merging SPOT panchromatic and multispectral image data. *Photogrammetric Engineering & Remote Sensing*, vol. 56, 4, pp. 459-467.

Chavez, P.S.Jr., Sides, S.C. and Anderson, J.A., 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. *Photogrammetric Engineering & Remote Sensing*, vol. 57, 3, pp. 265-303.

Mangolini, M., Ranchin, T. and Wald, L., 1995. Evaluation de la qualité des images multispectrales à haute résolution spatiale dérivées de SPOT. *Bulletin Société Française de Photogrammétrie et Télédétection*, 137, pp. 24-29.

Ranchin, T. and Wald, L., 1993. The wavelet transform for the analysis of remotely sensed images. *International Journal of Remote Sensing* , 14, 3, pp 615-619.

Ranchin, T., and Wald, L., 1995. Fusion d'images HRV de SPOT panchromatique et multibande à l'aide de la méthode ARSIS : apports à la cartographie urbaine. To appear in actes des sixièmes journées scientifiques du réseau Télédétection de l'AUPELF-UREF : Télédétection des milieux urbains et périurbains, Liège, Belgique, 2-5 octobre 1995.